Geology of the Greater Fermilab Region

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ABSTRACT

This paper reviews the general geology and geotechnical characteristics of the greater Fermilab region. The area described is roughly 60 by 70 km, or 30 km north and south, and 10 km east and 60 km west of Fermilab. Necessary information is presented for evaluating the feasibility of constructing tunnels and chambers for any type of new accelerator construction in connection to Fermilab.

I. GEOLOGIC/GEOTECHNICAL DATA SOURCES

Considerable information is available for this region. Nearly 8,000 borings have been described in the area. Other resources include geologically-based county planning studies; site-specific studies, such as the investigation of the original Fermilab site, and its additions which will go down into bedrock; and investigations performed over 5 years for Illinois' proposed Superconducting Super Collider (SSC) site. Under law, the Illinois State Geological Survey (ISGS) maintains a very large file, available to the public, of the geologic description and samples from water wells throughout the state. Along with geotechnical boring information from the Illinois Department of Transportation for bridges, and other siting studies for schools and commercial industry, these resources provide not only a detailed three- dimensional understanding of the geology of the area but also of the physical properties, and groundwater sources and quality.

Area geology and its uniformity have also been verified through seismic profiles with 160 km of lines. This technique is also used to detect faults through observing the displacement of the bedrock strata at depth.

The physical properties of the soils (glacial material) resting on the bedrock are known from the many strength characteristic tests run for the original Fermilab siting and for bridge foundations. Also the ISGS performs many other tests and particle size analyses on the glacial deposits. The physical characteristics of the bedrock are known from the many strength tests on rock samples and field observations made on joint directions and length.

The geological work done in the 1960s to site what became Fermilab, the many regional studies done since, and especially the massive body of geological information assembled in association with the proposed SSC project, was published and is therefore readily available for any of the several potential new accelerators now under discussion. Detailed descriptions and associated laboratory data from 78 test holes drilled for projects and potential projects at Fermilab were added to the files and archives of the ISGS.

II. STRATIGRAPHY OF NORTHEASTERN ILLINOIS

The general geology of northeastern Illinois is glacially derived deposits overlying bedrock. The surface drainage, topography, and type and location of glacial drift materials were largely produced by erosion and deposition by glacial ice and running water. The layered bedrock lies below the glacial drift at depths generally ranging from 15 to 92 m. Locally along the Fox River valley, the glacial materials are less than 15 m thick, with bedrock exposed in quarries, along streams and in roadcuts.

A. Glacial Deposits

The glacial deposits can be broadly categorized either as materials deposited directly from the melting glacier, a mixture of pebbles and cobbles in a matrix of clay, silt, and sand (till); or as materials carried out from the glacier by the meltwater and redeposited along meltwater rivers (sand and gravel called outwash). The silt and clay (lacustrine deposits) settled out in quiet-water lakes and ponds. Also present are windblown sand and silt (loess), recent river deposits (alluvium), slopewash (colluvium), and peat and muck.

Of these deposits, glacial till and outwash predominate. Glacial tills can be identified by dominant grain size and mineralogic characteristics and by their compressive strengths that are higher than other materials overlying the bedrock. Where the bedrock is near the surface, only one till may be present. In the thicker drift areas, several tills as well as outwash and lacustrine deposits may be present. The foundations of the accelerators now operating at Fermilab and the upgrades currently under construction are in glacial tills. For each of the several potentially much larger accelerators that might be considered for the Fermilab site, an expansion of the current accelerator complex into bedrock tunnels and chambers is a reasonable and economical possibility.

B. Bedrock

The bedrock layers that are important with respect to tunnels and chambers include, from top to bottom, the Silurian dolomite, Maquoketa dolomitic shale, and the Galena-Platteville dolomites. A water bearing sandstone that is primarily used for industrial water supplies lies below.

The dolomite layers of the Silurian are the uppermost bedrock near Fermilab. These are massive, pure to slightly clayey fine-grained dolomites, up to 61 m thick on the eastern part of the area. This is the layer that the TARP (Tunnel and Reservoir Plan of Chicago and its suburbs) tunnels are cut through. The Silurian dolomite thins to the west and is absent from about the middle of the study area and westward. It is underlain by the Maquoketa dolomitic shale, which is at the bedrock surface where the Silurian is absent. It is a dolomitic shale that is interbedded with clayey dolomite. The dolomite cement in the shale makes this unit strong and resists weathering (falling apart). The Maquoketa shale is 15 to 61 m thick in this area. The Galena-Platteville dolomites are massive layers, with areas of limestone. They are 91 to 107 m thick in the area and are the top of bedrock in the extreme western part of the area where the Maquoketa thins and is absent.

C. Structures

The bedrock layers generally dip to the east-southeast about 5 to 7 m per km. The only known fault in the area is the Sandwich Fault zone which is located to the extreme southwest. This fault is known to be inactive and extends in a northwest-southeast direction for a distance of about 26 km. The zone is 0.8 to 3 km wide of nearly vertical faults [1]. The only other fault type structures are two possible minor offsets of up to 4 m were found in the top of the Galena dolomite during the 162 km of seismic refraction and reflection surveys run in the area [2].

Two dominant systematic joint sets have been identified in the area, one trending roughly northeast-southwest and the other northwest-southeast. Foote [3] and Bauer and others [4] mapped joint directions in quarries of the area and with the use of angled boreholes. These joints are nearly vertical and the long continuous ones are spaced 162 m apart or more.

Joints appear to be more open near the bedrock surface and are locally stained to depths of about 30 m. Most of the near-surface joints have widths or apertures ranging from hairline cracks to a fraction of a centimeter. A few display greater widths or apertures, particularly those close to the bedrock surface, where slight solution widening has occurred.

III. HYDROGEOLOGY

Four major hydrogeologic systems are present in the area. These can be described informally as the (1) drift/upper bedrock aquifer, (2) the Maquoketa aquitard and Galena-Platteville dolomites which are very tight and inhibit water movement, (3) sandstone aquifers below the Galena-Platteville dolomites (the Ancell and Ironton-Galesville), and (4) deep sandstone aquifer, the Mt. Simon Sandstone. The aquifer closest to the ground surface is found in both the glacial drift and bedrock since they are in contact with each other and the top of bedrock is water bearing in the upper 15 to 23 m where the joints are more open and the top of bedrock fractured from glacial movement.

Glacial drift aquifers are not commonly used as sources for large supplies at the present. Exploration and exploitation of drift aquifer resources has increased recently, however, with several municipalities attempting to use this source to supplement their water supplies. There are extensive drift aquifers along the Fox River Valley, particularly in the south. Well yields from this source as great as 1,900 liters per minute are not unusual [5].

Water from the bedrock is obtained from the upper bedrock aquifer and the lower sandstones. The upper bedrock aquifer is extensively used in the eastern part of the area where the thick Silurian dolomite is directly below the drift. Wells may yield as much as 3,800 liters per minute, although the average yield is much less. The aquifer in these areas has been developed for public water supplies as well as private uses.

To the west, shale and dolomite of the Maquoketa are the uppermost bedrock below the drift. The Maquoketa dolomite is similar to Silurian dolomite, but where shale comprises the surficial bedrock, joints and fractures are fewer and do not extend as deep, due to the softer and less brittle nature of the shale. Groundwater conditions in the shaley part directly below the drift are not as favorable as dolomite for developing groundwater supplies.

The Ancell Group sandstones provide small to medium yields (190-760 liters per minute) throughout the region. They are often used for domestic and small industrial supplies where the Maquoketa or Galena-Platteville are the top of bedrock below the drift. They are not commonly used for municipal supplies because their yield is limited.

The deep sandstone aquifer of the Ironton-Galesville provides large water supplies throughout the region. It is the most uniform and productive zone, commonly with well yields of more than 1,900 liters per minute. It is the source for industrial supplies [6].

The Mt. Simon aquifer is not as extensively used as a source because of its greater depth and lesser yields. Water quality deteriorates rapidly at elevations lower than -600 m below mean sea level, where total dissolved solids rise from 1,000 to 50,000 mg/L.

IV. TUNNELING AND CHAMBER EXCAVATION

The uniformity and general excellent quality of the rock formations in the area with respect to underground construction are clearly demonstrated by the Tunnel and Reservoir Plan (TARP) project which encountered virtually no geologic surprises or major geotechnical problems. With over 162 km of 2 to 10.75 m diameter tunnels bored in dolomite bedrock in the area, contracts are usually finished under budget and ahead of schedule. Many world records for tunnel boring machine (TBM) advance rates were achieved in boring these tunnels. Also because of the extensive tunneling experience in these dolomites, bids on contracts let for the projects have been under engineers' estimates by up to 45% [7]. The latest contract is 20.6% under engineers' estimates [8]. The uniform, stable, strong dolomite along with the extensive tunneling experience is the reason for the low tunnel costs.

A. Tunnel Boring Machine Advance Rates

The overall advance rates for tunnel boring machines (TBMs) are dependent on how fast the rock can be cut (penetration rate), the rate at which the cut rock fragments can be removed (muck removal), the amount of time that the TBM is actually cutting the rock (percent machine utilization) and the number of shifts and their hours worked per day (three 8-hour shifts versus two 10-hour shifts per day). An "average advance rate" incorporates all of these factors. Friant [9] provides additional information on TBMs and other tunneling methods.

The TARP average tunneling advance rate is 2.3 m per hour or 55 m per day [7] in dolomite which is about twice as strong as the Galena-Platteville dolomites. In the Galena-Platteville dolomites, it is conservatively estimated using today's tunneling technology, that average advance rates of over 60 m per day can be achieved. One of the limiting factors restricting how fast the TBM can cut into the rock, appears to be the rate at which the amount of muck (excavated rock material) can be removed from the cutting machine.

B. Chambers or Experimental Halls

The TARP Mainstream System Pump House caverns provide a useful and relevant example of constructing large chambers underground in rock. These are the largest and deepest chambers in northeastern Illinois. They are rectangular in plan, 94 m long, 30 m high, and 20 m wide, and 110 m below ground. Because of the excellent rock conditions these chambers were mined out in 9 months each, several months ahead of schedule [10]. The chambers are elongate N-S to bisect the two joint sets, producing the most stable chamber sidewalls. Also, the bedrock in this area is under the highest compression in roughly an east-west direction. This compression on an arched roof chamber that is elongate north-south helps to hold up the roof rock.

Chambers are excavated with conventional drill-and-blast using the top heading and bench method. The rock is first excavated at the roof of the cavern. Bolts are placed to support the rock, then a more permanent support of reinforcing wire and concrete is installed on the arched roof. Then mining continues by taking out benches (layers) of rock as the chamber is mined out from top to bottom. As each layer is removed, support is added to the side walls. Previous analysis showed that chambers wider than 38 m can be accommodated in the dolomites [11].

C. Issues of Siting a Tunnel

There are a number of important issues for siting a tunnel for an accelerator. Groundwater and vibrations are discussed below. The geotechnical properties of all of the materials proposed to host new tunnels have been extensively documented [4]. All of the siting issues were described in the State of Illinois proposal for the SSC project [11]. Curran and Bhagwat [12] described methods to utilize the material excavated from tunnel construction in the region of Fermilab. There are many markets for crushed dolomite in this region, therefore disposal is not a problem. The chemistry of the excavated material has been documented [13] as well as the natural background radiation in the area [14]. Increased tunnel depth does not increase costs, because it is cheaper to work in the highest quality rock layer rather than in the most shallow rock. An overview of the environmental issues of tunneling in Northeastern Illinois and several dozen maps in an atlas format were compiled by Hines [15].

1. Groundwater

For underground excavation, the groundwater issues are how much water will be encountered during excavation and operation of a facility, and whether the excavation will impact existing or future water supplies.

The placement of tunnels and chambers in non-aquifer units such as the Galena-Platteville dolomites greatly reduces water inflow but does not eliminate it. All rocks allow some flow of water through them. Tunnels in the Galena-Platteville dolomites on the east side of the study area would have very little sustained water inflow. Wells placed in this unit on the east side had no water accumulate over years of monitoring, because municipal and industrial use of the aquifers below the Galena-Platteville have greatly lowered the water pressures and levels. Tunnels on the west side may have water inflows of 117 to 235 liters per minute per km (or one and a half to three bathtubs worth per minute per km) of tunnel. These flow rates are very controllable.

Many municipalities and local homeowners with wells get their water from the upper aquifer that is in the drift and in the upper 23 to 30 m of bedrock. Monitoring wells throughout the area show no connection between this upper aquifer being used for water supplies and the ones a hundred meters or so below in the lower sandstone aquifers. Lowering of the water levels and pressures in the dolomites, above the lower sandstone aquifers, has not impacted the upper aquifers that people are using for water supplies. A tunnel down in the non-aquifer units will not impact the near surface aquifers.

2. Vibrations

The alignment of particles in an accelerator are critical to its success. Therefore, external vibrations and the amount of displacement caused by them are a site concern. The largest vibrations in the region of Fermilab are from truck and rail traffic. A study in this area [16] investigated this concern by monitoring vibrations from truck traffic over an expansion joint of a bridge and the passage of a freight train. Truck traffic showed displacements of 2.9 to 19.3 µm on the bridge abutment, however, 21 m down and 50 m horizontally to a rock quarry floor, these movements were attenuated 92 to 241 times down to 0.03 to 0.08 µm. The train traffic displacements on the ground next to the rail line were 1.6 to 4.06 µm; 18 m down and 58 m horizontally to the rock quarry floor, the displacements were attenuated 62 to 123 times down to 0.013 to 0.066 µm.

Another vibration source in the area is from several rock quarries that perform blasting during their operations. A site specific analysis of distance from the quarry to a proposed tunnel or experimental hall would be needed for any new project. Analysis for the proposed SSC in the area showed no concerns; vibrations were measured at several magnitudes below the SSC tolerances.

V. CONCLUSIONS

The greater Fermilab area is a geologically and geotechnically suitable location for siting various accelerators being contemplated today. The significant advantages of the geology and the area include: extensive exploration activities which have indicated minimal construction risk; favorable geologic conditions that allow flexibility for various accelerators; and extensive rock tunneling experience in the region, which increases the confidence of tunneling contracts, resulting in bids under engineering estimates and completion ahead of schedule.

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